(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
19 December 2002 (19.12.2002)

PCT

(10) International Publication Number
WO 02/101408 A1

(51) International Patent Classification[7]: G01S 5/14, 5/06

(21) International Application Number: PCT/AU02/00760

(22) International Filing Date: 12 June 2002 (12.06.2002)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
PR 5585 12 June 2001 (12.06.2001) AU

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(81) Designated States *(national)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, OM, PH, PL, PT, RO, RU, SD, SE, SG,

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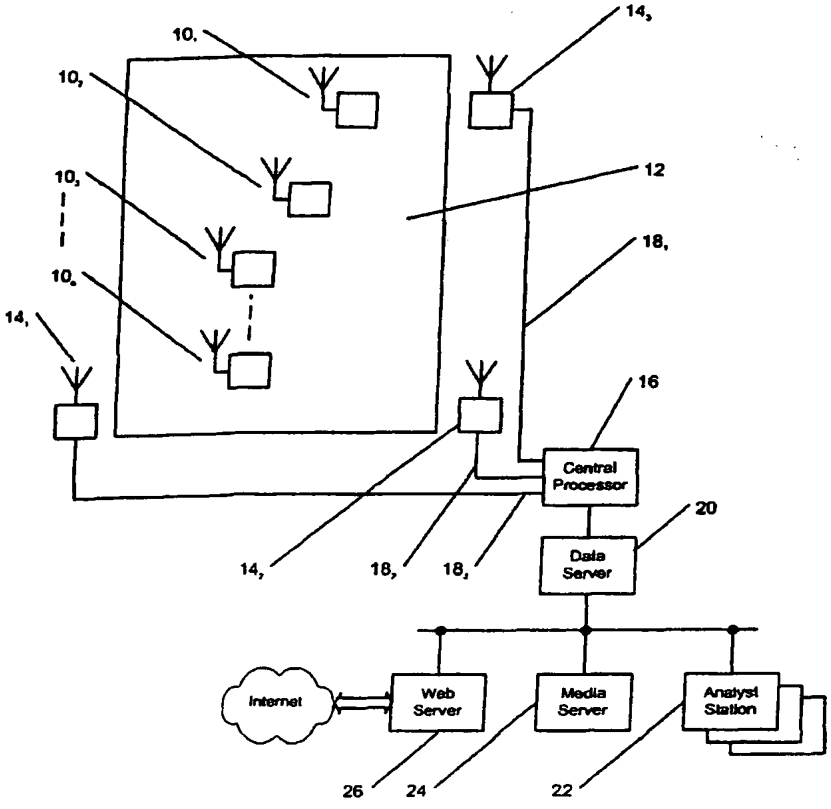
(54) Title: SYSTEM AND METHOD FOR MONITORING AND DISPLAYING ATHLETE CHARACTERISTICS



(57) Abstract: A system and method for monitoring and displaying characteristics of one or more athletes, the system including a plurality of tag devices, at least one tag being located on each athlete and being capable of periodically transmitting a tag device signal in the form of a short burst, frequency-hopped spread spectrum radio frequency signal. At least three separately located wideband receivers are capable of receiving a tag device signal and processing the tag device signal to provide data representative of the time of arrival of the tag device signal at the receiver. A centralised processing means receives and processes the time of arrival data from each receiver to determine the position of the tag devices using differences in the time of arrival data from each receiver. The positions determined by the centralized processing means are stored on a data server and are able to be retrieved and processed so as to enable a graphical representation of at least one selected athlete characteristic to be displayed.

WO 02/101408 A1

SI, SK, SL, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZM, ZW.

(84) **Designated States** *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

SYSTEM AND METHOD FOR MONITORING AND DISPLAYING ATHLETE CHARACTERISTICS

Field of the Invention

The present invention relates to a system and a method for monitoring and displaying characteristics, such as positional and physiological characteristics, of athletes. The invention finds particular use in the monitoring and display of characteristics of one or more athletes during competition.

Background of the Invention

Real time monitoring of the characteristics of athletes during competition is of relevance to sports broadcasting, specialist coaching and sports medicine. For example, in the sports broadcasting industry, it is widely accepted that the presentation of information which enables, for example, the analysis of an athlete's performance, or an assessment of team tactics in real time, enhances the broadcast of a sporting event.

Similarly, and in terms of specialist coaching techniques, the post match analysis of an athlete's performance by reviewing, for example, video footage and statistical data of an athlete's, or a team's, performance throughout the course of a sporting event, is now a recognised technique for the retrospective assessment of an athlete's, or a team's, performance.

Hence, with the increase in popularity of sports broadcasting, due in part to the advent of the Internet and cable television, and with the increasing professionalism of sports coaching, various kinds of systems have been developed to provide data which can be used to convey athlete characteristics to a viewer (for example, to a spectator or to a coach).

Previous attempts at developing such systems have typically been limited to only being able to provide positional information of athletes. In broad terms,

such systems may be classified into one of a variety of types, namely, manually operated tracking systems, GPS systems, video processing systems and terrestrial electromagnetic systems.

Manually operated tracking systems provide a system for tracking single athletes, whereby an operator equipped with a pointing device (for example, a mouse) and a device for recording the movement of the pointing device replicates the two dimensional motion of an athlete on a playing field by moving the pointing device over a graphical representation of the playing field in accordance with the athlete's position.

GPS location systems are systems which utilise reference signals transmitted by a plurality of LEO satellites to obtain the three-dimensional position and velocity of an object. Whilst GPS systems provide the capability to provide positional data in an outdoor environment, the reliance of such systems on the reception of signals from the plurality of LEO satellites renders these systems unsuitable for use in an indoor environment such as an indoor sporting facility.

Video processing systems typically utilise video signals generated by a plurality of cameras and, using real time video signal analysis techniques, are able to track and display the positions of multiple athletes and possibly provide statistical data. In one example of a system of this type, consecutive video images of a sporting field are 'captured' and compared so as to identify regions of motion which correspond to the motion of athletes participating in the sporting event. In terms of the presentation of statistical data, such a system may be able, for example, to generate a graphical representation of the frequency and/or duration that an athlete occupies a particular region of a playing area. However, systems of this type are typically unable to also provide physiological data, if necessary.

Conventional terrestrial electromagnetic location systems involve the processing of identifiable radio frequency signals which propagate between a device at a known position and a device at an unknown position. In general terms,

conventional terrestrial electromagnetic location systems utilise either propagation delay measurements (for example round trip, or time of arrival) or the determination of the direction of maximum response of a received signal (using, for example, goniometric receivers) to determine the location of an object relative to one or more objects at known positions.

Although conventional terrestrial electromagnetic location systems may be better suited to monitor athlete position, these systems are highly susceptible to performance degradation due to multi-path effects and electromagnetic interference caused by extraneous electromagnetic emitters contiguous to the location system. Furthermore, multi-path effects may corrupt the integrity of an identifiable signal and therefore the location measurements. Since multi-path effects are most pronounced in locations which are contiguous to large structures such as, for example, a sports stadium, conventional terrestrial electromagnetic systems are generally unsuitable for use in a sporting facility.

Therefore, to date there has not existed an integrated system which provides a reliable and robust system and method for monitoring and displaying characteristics, such as positional and physiological characteristics, of one or more athletes during competition. It is thus an aim of the present invention to provide a reliable and robust system that can be used to provide real time acquisition, processing and display of characteristics, such as positional and physiological characteristics, for one or more athletes during competition.

Summary of the Invention

The present invention provides a system and a method for monitoring and displaying characteristics of one or more athletes, the system including:

(a) a plurality of tag devices, each tag device being capable of periodically transmitting a tag device signal in the form of a short burst, frequency-hopped spread spectrum (FH-SS) radio frequency (RF) signal, at least one tag being located on each athlete;

(b) at least three separately located wideband receivers, each receiver being capable of receiving a tag device signal and being capable of processing the tag device signal to provide data representative of the time of arrival (TOA) of the tag device signal at the receiver;

(c) a centralised processing means capable of receiving and processing the TOA data from each receiver to determine the position of the tag device using differences in the TOA data from each receiver;

(d) a data server capable of storing the positions determined by the centralized processing means; and

(e) a means for retrieving and processing data from the data server to enable a graphical representation of at least one selected athlete characteristic to be displayed.

Although reference has been made to calculating the position of only athletes having tag devices, it should be appreciated that the invention is not to be so limited. Indeed, tag devices capable of periodically transmitting a short burst, frequency-hopped spread spectrum (FH-SS) radio frequency (RF) signal may also be affixed to other people (for example, a referee), a ball, and/or other sports related components (for example, a goal) to enable the system to determine the position of these objects, possibly relative to one or more athletes.

Reference to the term 'periodically transmitting' throughout this specification is to be understood to be reference to the transmission of a tag device signal at a predetermined rate (herein referred to as the 'pulse repetition frequency', or PRF). Furthermore, reference in this specification to the term 'short burst' is to be understood to be reference to a radio frequency signal having a duration which is typically less than 100 microseconds. For the purpose of this specification the duration of a short burst will be referred to as the 'pulse width'.

In a preferred form of the invention, the PRF of the tag device signal will be approximately 100 pulses per second. However, it is to be understood that

higher or lower PRF's may also be used, the actual PRF being somewhat dependent upon the actual pulse width of the short burst.

It is preferred that the PRF be different for each of the one or more tag devices. Ideally, the PRF of a tag device signal will be controlled by an electronic switch means included with the tag device. Advantageously, the electronic switch means will be able to provide a tag device signal having a leading edge with a 'very fast' rise time. In this respect, reference to the term 'very fast' is to be understood to be reference to a rise time which is typically less than 3 nanoseconds.

In terms of a system in accordance with the present invention that includes multiple tag devices, the transmission of a tag device signal by any one of the multiple tag devices preferably occurs asynchronously in time (for example, offset) and/or frequency (for example, tag device signals having different carrier frequencies) with the transmission of tag device signals by other tag devices. Advantageously, by using an asynchronous scheme, together with a nominal, as opposed to a system wide PRF, a system in accordance with the present invention is provided with the capability to operate in a highly dense tag signal environment by reducing the likelihood of tag device signals coinciding, and therefore interfering.

A tag device signal may include a portion which has been modulated by a binary data signal (referred to as the 'modulating signal') using a suitable binary modulation scheme which may include binary data which is at least representative of a tag device identifier.

In this form of the invention, the system will be able to monitor and display positional characteristics of one or more identified athletes together with athlete identification information (for example, an athletes name and/or number and/or team). In this respect, positional characteristics may include athlete spatial position (for example, 2D or 3D spatial position) and/or time derivatives of

athlete spatial position (for example, velocity and acceleration) during competition.

In yet another form of the invention, the modulating signal may further include data which is representative of physiological characteristics of an athlete having a tag device. In this form, in addition to monitoring and displaying the aforementioned athlete positional characteristics and identification information, a system in accordance with the present invention may also be able to monitor and display athlete physiological characteristics such as heart rate, skin temperature and relative humidity.

Such physiological characteristics may be measured using one or more transducer means, which in a preferred form will be incorporated within the tag device. Alternatively, the transducers may be located external to the tag device and thus interface to the tag device via an electrical interface means. The one or more transducer means may be periodically sampled using a multi-channel analog to digital converter and conditioning means provided with the tag device.

In this specification, reference to the term 'wideband receivers' is to be understood to be reference to a receiver having a bandwidth which is at least as wide as the frequency band used to transmit the tag device signals. In this respect, it is preferred that the bandwidth of the receivers is sufficient so as to not degrade the rise time of the tag device signal.

It is preferred that the receivers used in the system of the present invention will be able to down-convert tag signals without knowledge of the spreading sequence used to generate the FH-SS tag device signal.

Each separately located wideband receiver will be preferably located contiguous to a sporting facility in which the one or more athletes are competing, and will preferably include:

(a) a means for sensing a tag device signal;

(b) a means for down-converting the tag device signal to an intermediate frequency (IF) signal;

(c) a means for digitising the IF signal to provide a digital signal which is representative of the pulse envelope (herein referred to as the video signal) of the down-converted signal; and

(d) a means for processing the video signal to provide data which is indicative of the TOA of a received signal at a receiver;

(e) a means for decoding the video signal to recover data corresponding to the modulating signal; and

Furthermore, each wideband receiver will preferably also include a high stability, high speed counter which is able to generate a timing signal which is synchronised with a master clock provided with the centralised processing means.

In this specification, reference to the term 'contiguous' is to be understood to be reference to the positioning of the receivers in the vicinity of a sporting facility such that the receivers are dispersed about the sporting facility and located so as to be able to receive tag device signals emitted from tag devices located within the boundaries of the sporting facility. In this respect, reference to the term 'sporting facility' is to be understood to be reference to any space in which athletes are able to compete, and includes two dimensional and three dimensional spaces, together with open or closed facilities.

In relation to the processing of the tag device signals, the TOA of a received signal is preferably determined using the leading edge of the video signal by a comparator means which compares an attenuated version of the digital signal with a delayed version of the same signal to provide a trigger signal which is used to capture the current count of the timing signal.

Advantageously, this technique provides the system of the present invention with a simple and robust technique for reliable TOA measurement, since this

technique is largely independent of amplitude and rise time variations of the video signal, and provides improved noise immunity.

Apart from receiving and processing tag device signals, the wideband receivers are preferably also able to communicate tag device data (that is, TOA and decoded data) to the centralised processing means via a communications link.

The centralised processing means preferably compiles data received from each receiver, groups the tag device data on the basis of tag device identification data and the TOA, calculates the differential time of arrival (DTOA) using the TOA data for each grouping to provide DTOA data, and calculates the spatial position of the one or more athletes based on the DTOA data, using statistical functions and hyperbolic fixing techniques to provide athlete's positional data.

The positional data, together with any associated athlete identification and physiological data, is preferably stored on the data server. The means for retrieving and processing data from the data server preferably enables a graphical representation of at least one selected athlete characteristic to be displayed in real time.

The present invention also provides a method for monitoring and displaying characteristics of one or more athletes having a tag device capable of periodically transmitting a short burst frequency-hopped spread spectrum (FH-SS) radio frequency (RF) signal, the method including:

(a) receiving a tag device signal using at least three separately located wideband receivers;

(b) processing the tag device signal to provide data representative of the time of arrival (TOA) of a tag device signal at each receiver;

(c) processing the TOA data to determine the position of the tag device using differences in the TOA data from each receiver;

(d) storing the positions on a data server; and

(e) retrieving and processing data from the data server to enable a graphical representation of at least one selected athlete characteristic to be displayed.

In a preferred form of the present invention, positional and physiological data stored on the data server is able to be post processed to provide the capability to replay selected characteristics of a selected athlete, or athletes. The replay capability may be used, for example, to enable the replay of one or more selected athlete, or athlete's, characteristics during a particular event (for example, the motion of a football player used to evade an attempted tackle by an opposing player) for a particular time interval, or to enable statistical analysis and display of the stored data (for example, the average heart rate of a particular athlete over some interval).

Hence by using a system in accordance with the preferred form of the present invention, an operator will be able to analyse, either in real time or in replay, positional and physiological characteristics of one or more identified athletes participating in competition. Furthermore, the present invention will provide an operator with the ability to analyse interactions between one or more athletes and other objects (for example, the position of an athlete with respect to a ball, or the goals).

It is envisaged that the present invention will find particular application in the areas of sports media (for example, television or Internet broadcasting of sporting events) and/or for use as a specialist-coaching tool.

Brief Description of the Drawings

The invention will be now be described in greater detail by reference to the attached drawings which illustrate a preferred embodiment of the invention. It is to be understood that the particularity of the following description is not to limit the generality of the above description of the invention.

In the drawings:

Figure 1 shows a system block diagram of an athlete monitoring system in accordance with a preferred embodiment of the present invention;

Figure 2 shows a tag device suitable for use in the embodiment of Figure 1;

Figure 3 shows a block diagram of a receiver sub-system suitable for use in the embodiment of Figure 1;

Figure 4 shows a block diagram of a TOA detector suitable for use in the embodiment of Figure 1;

Figure 5 shows a block diagram of a main processor sub-system suitable for use in the embodiment of Figure 1; and

Figure 6 shows an example of a graphical user interface (GUI) suitable for use in an analyst station suitable for use in the embodiment of Figure 1.

Detailed Description of the Invention

The preferred embodiment of the invention relates to the use of an athlete monitoring and display system that can be used to monitor and display athlete characteristics, such as positional and physiological characteristics of one or more athletes, and possibly the positional characteristics of one or more other objects having a tag device (for example, a ball) during a sporting competition.

As is illustrated in the block diagram of Figure 1, the preferred embodiment of the present invention includes a plurality of tag devices 10, one or more of which may be associated with one of a number of athletes (for example, basketball players), or other object (for example, a basketball), to be monitored in a monitored environment 12 (for example a basketball stadium) during competition (for example, a basketball game).

In this respect, reference to the term 'monitored environment' is to be understood to be reference to a facility, such as a sporting facility, and may be an enclosed facility or an open facility. Furthermore, although reference has been made to the use of the system in terms of the monitoring of athletes, and possibly other objects, during competition, it should be appreciated that the invention may equally be used to monitor the athletes, and the other objects, during non-competitive events (for example, during training and/or practice sessions).

At least three wideband receivers 14, located contiguous to the monitored environment, are able to receive tag device signals and process a received signal to determine the TOA of a received signal and demodulate encoded data.

It will, of course be appreciated that more than three wideband receivers 14 may be used, the number being somewhat dependent on the nature and size of the monitored environment. Indeed, the more wideband receivers in place, the more accurate (and the less susceptible to interference) the system will be.

A central processing unit 16 is electrically coupled to each wideband receiver 14 via a communications link 18 and receives TOA and demodulated data from each of the wideband receivers 14. The central processing unit 16 processes the TOA and demodulated data to provide athlete characteristics. A data server 20 stores the athlete characteristics, in the form of digital data, wherefrom analysts stations 22, a media server 24 or a Web server 26, or a combination thereof, are able to retrieve and/or enable the display of graphical

representations of the digital data, either on a local or remote display device (for example, via an Internet connected device).

With reference now to the preferred embodiment of a tag device 10, and as is illustrated in Figure 2, each tag device 10 includes a controller 30, an up-converter 32, a digitally controlled oscillator 34, a channel number generator 36 (which in the preferred embodiment of the invention is a pseudo random binary sequence (PRBS) generator), a multi-channel analog to digital converter (ADC) 38, a local memory 40, a bandpass filter 41, a RF amplifier 42, antenna 44, a battery (not shown) and a casing (not shown). In a particularly preferred form of the tag device 10, the tag device casing is flexible, enabling the tag device to be fitted to the body of an athlete.

In the preferred embodiment of the invention, the controller 30 may be a dedicated application specific integrated circuit (ASIC). In this form, the controller 30 may be implemented using a single package, having a small physical size (for example, an ASIC). Alternatively, in tag devices where the size of the tag device is not constrained by design requirements, the controller 30 may be implemented using a digital computer, or a programmable gate array, together with peripheral components (for example, program memory) and associated program instructions, preferably in the form of a compiled software program.

Ideally, the ADC 38 is able to interface to a plurality of transducers (not shown) some, or all of which, are able to be coupled to an athlete to enable the monitoring of physiological characteristics (for example, heart rate). In a particularly preferred embodiment of a tag device suitable for use in the present invention, the transducers may be mounted within the tag device casing.

The tag device 10 may be able to interface to a variety of transducer types. Hence, the selection of a particular transducer, or set of transducers, may be based on the demands of the particular sport in which a monitored athlete is competing, or for the purposes of monitoring a specific physiological parameter,

or some other consideration. In one example, when a monitored athlete is competing in an endurance sport (for example, a long distance track event) the system may be configured to monitor pulse rate, respiratory rate and possibly other parameters.

The up-converter 32, the bandpass filter 41, the RF amplifier 42 and the antenna 44 perform functions that would be normally attributed to them in a RF transmission system. In the preferred embodiment of the tag device 10, each of these components has a bandwidth of at least 100 MHz and an operating frequency of approximately 2.400 GHz to 2.463 GHz. In other embodiments of the invention, components having a lower bandwidth may be used. Indeed, the applicant envisages that components having a bandwidth of 25 MHz may be used. Similarly, other operating frequencies may be used.

Having described the components of a tag device 10, the process of generating a tag device signal will now be described.

In the preferred embodiment of the present invention, each tag device 10 periodically and autonomously transmits a binary modulated FH-SS signal at a notional PRF of 100 Hz and with a duty cycle of approximately 1:10.

Here, the controller 30 uses a high speed switching device (for example, a PIN diode) to switch a 400 MHz signal (herein referred to as the 'bandpass signal') 'on' and 'off' at the notional PRF, whereby each switching operation (that is, switching the bandpass signal 'on' and 'off') provides a short burst 400 MHz signal having a very fast leading edge. Although the preferred embodiment has been described as employing a 400 MHz bandpass signal, it is to be understood that other frequencies may be used (for example, a bandpass signal between 100 MHz and 400 MHz).

During the portion of the switching cycle when the bandpass signal has been switched 'on', and after a predetermined time delay, the controller 30 may modulate the switched bandpass signal using a binary modulation scheme (for

example, on-off keying (OOK) or binary phase shift keying (BPSK)) and a binary modulating signal, to provide a modulated signal.

Preferably, the binary modulating signal will be constructed by controller 30 and may include tag device identification data, in the form of a multi-bit digital word, which has been retrieved from local memory 40 (for example, an EPROM or FLASH memory) and digital data which has been read from the ADC 38. In the preferred form of the present invention, the controller 30 may construct the modulating signal in the form of a time division multiplexed (TDM) frame which includes sampled DAC values and a tag device identifier digital word and possibly other data, in the form of interleaved multi-bit digital code words.

The modulated signal is up-converted by the up-converter 32 to an up-conversion band which is dependent upon a signal (herein referred to as the carrier signal) generated by the digitally controlled oscillator 34. Here, the PRBS generator 36 preferably provides a code sequence, having a fixed sequence length, which is input into the digitally controlled oscillator 34 synchronously with a timing signal from the controller 30 which is itself synchronous to the switching 'on' of the bandpass signal. Indeed, in one embodiment of the invention, a signal used to enable the switching of the bandpass signal may be used as the timing signal for the PRBS generator 36.

In response to a particular code from the PRBS generator 36, the digitally controlled oscillator 34 provides a carrier signal, having a particular frequency, wherein the particular frequency has a dependency on the particular code input to the digitally controlled oscillator 34.

In the preferred embodiment, the frequency of the carrier signal 'hops' between one of 256 discrete frequencies within the band 2.400 GHz to 2.463 GHz. That is, in the preferred embodiment of the tag device 10, the PRBS code sequence consists of 256 discrete code words, each of which corresponds to a particular carrier signal frequency selected from the band 2.400 GHz to 2.463 GHz, in discrete steps of approximately 250 kHz.

With reference to Figure 3, there is illustrated a preferred embodiment of a wideband receiver 14. As is illustrated, in the preferred embodiment of a wideband receiver 14 that is particularly suited for use in a system of the present invention, a receiver includes an antenna 46 for sensing tag device signals, a RF amplifier 48, a bandpass filter 50, a multi-stage down-converter 52 (which for the purposes this description will be represented as a mixer 54 and a frequency stable local oscillator (LO) 56), an analog to digital converter (ADC) 58 and a digital pulse processor (DPP) 60.

Preferably, the antenna 46 for sensing tag device signals has a gain pattern which is optimised to provide near constant gain over the monitored environment 12. Advantageously, by utlising an antenna with this gain pattern, a receiver 14 is provided with the capability to attenuate signals which are outside the field of view of the antenna 28.

The antenna 46, the RF amplifier, the bandpass filter 50 and the multi-stage down-converter perform functions that would be normally attributed to them in a RF receiver system. In the preferred embodiment of the receiver 14, each of these components has a bandwidth of at least 100 MHz and an operating frequency of approximately 2.400 GHz to 2.463 GHz.

In the preferred embodiment of the receiver 14, the ADC 58 is a 12 bit, 200 Mbps analog to digital converter with an input bandwidth greater than 400 MHz, preferably 500 MHz.

In operation, a tag device signal received by a receiver 14 is amplified using the RF amplifier 48 and filtered using the band pass filter 50 to attenuate signals outside the desired band. The multi-stage down converter 52 down-converts filtered signals to an Intermediate Frequency (IF). In this respect, all tag device signals received by a receiver 14 are able to be down-converted to an IF signal using a local oscillator 56 having a fixed frequency. In this form, as will be appreciated by those skilled in the art, the tag device signal is not 'despread' by

the receiver using spread spectrum correlation techniques. Instead, all signals within the desired frequency band are down-converted to a different IF using the same LO frequency.

IF signals are digitised by the ADC to provide a multi-bit digital representation of the IF signal for processing by the DPP 60.

With reference to the DPP 60, the DPP 60 may be a digital computer with appropriate digital pulse processing algorithms, which provides the requisite functionality of a pulse envelope detector 62, a data demodulator 64 and a TOA detector 66 (refer to Figure 4).

Responsive to the digitisation of an IF signal, the pulse envelope detector 62 provides in-phase (I) and quadrature (Q) multi-bit digital output signals which are able to be utilised by the pulse envelope detector 62 to provide an output signal (herein referred to as the video signal) which is proportional to the envelope of the IF signal using a square law envelope detection process.

As is diagrammatically illustrated in Figure 4, the TOA detector 66 attenuates the video signal using a 3dB attenuation function 68 and compares, using a comparator function 70, the attenuated signal to the magnitude of a version of the video signal which has been delayed using a delay function 72 having a predetermined delay. Ideally, the predetermined delay will be selected to avoid any overshoot and ringing which may be associated with the leading edge of the video signal and be greater than the maximum rise time, but less than the minimum pulse width, of a short burst.

In response to detecting that the amplitude of the delayed signal has 'crossed' the amplitude of the attenuated signal, the comparator function 70 provides a trigger signal which coincides with the 3dB point of the leading edge of the video signal. The trigger signal, may be used to sample the count on a free running high precision counter 74, which is synchronised with a master clock

provided by the central processing unit 16 and which is interpreted as the TOA of the received signal.

In operation, a relative offset between the free running high precision counter 74 provided with each receiver 14 and the master clock 75 is determined as a part of a system calibration process which may involve positioning tag devices 10 at known locations in the monitored environment, receiving tag device signals from the positioned tag devices, and comparing the count of the master clock 75 and the free running high precision counter 74.

Advantageously, this technique provides the present invention with the capability to precisely determine the TOA of a received signal with respect to a common reference point on the leading edge of a received signal (that is, the 3dB point), irrespective of the amplitude of the received signal. Hence, the precision of the TOA detection process is retained for signals of varying amplitudes.

Contemporaneously with the TOA processing, the digitised IF signal is demodulated using the data demodulator function 64 to decode any data which may have been modulated onto the received signal. Here, the data demodulator reconstructs the modulating signal used to encode the tag device signal, thus recovering the binary data.

Following the determination of the TOA of a received signal and the demodulation of data associated with the received signal, the DPP 60 formats both the TOA data and the demodulated data into a format (herein referred to as the tag device data) suitable for transmission to the centralised processing unit 16 using a communications controller device 73.

With reference now to the central processing unit 16, as is illustrated in Figure 5 the central processing unit includes a router 76, one or more digital signal processors (DSP) 78 and a master clock 79.

The router 76 is electrically coupled to the at least three receivers 14 via a communications link 18 and is able to receive tag device data from each receiver 14 for the one or more tag devices 10. In the preferred embodiment of the invention, the communication link may be a high speed fibre optic or broad band RF link.

The master clock 75 is electrically coupled to the at least three receivers 14 to provide a reference clock signal which is used by the receivers 14 to clock the high precision counters 74.

Responsive to the receipt of tag device data, the router 76 is able to sort the tag device data according to the tag device identifier and the TOA data. Where tag device data received from a particular receiver includes a tag device identifier, the router 76 'bins' (that is, groups) the tag device data with tag device data received from other receivers for the same tag device 10. In this respect, reference to the term 'bins' is to be understood to be reference to grouping tag device data according to the particular tag device and the TOA data.

In the preferred embodiment of the router 76, where a tag device signal has been interfered with on route to a particular receiver 14 to the extent that the portion of the tag device signal carrying the tag device identifier is corrupted, the router 76 may be able to allocate the corrupted signal to an appropriate bin on the basis of the TOA using a 'temporal window'. That is, if the TOA of the corrupted signal occurs within a 'temporal window' which includes TOA data from an identified tag device, whereby the corrupted signal TOA is separated from TOA data for other identified tag devices by an interval which exceeds a particular threshold, then the router 76 may bin the corrupted TOA data with the identified tag device data. In the preferred embodiment of the router, the particular threshold may be the maximum propagation time for a tag device signal to traverse the monitored environment to a particular receiver 14.

The tag device data bins are then communicated to a particular DSP 78, wherein a particular DSP 78 is assigned to a specific tag device identifier or set

of tag device identifiers. In this respect, in the preferred embodiment of the system of the present invention there is provided multiple DSPs 78, whereby the multiple DSPs are configured in a modular arrangement which is scalable to suit the number of athletes being monitored.

Upon receipt of the binned tag device data, a DSP 78 calculates differential time of arrival (DTOA) data for each pair of receivers 14. In a preferred embodiment of the invention the DTOA data for a particular tag device 10 may be calculated using a statistical function whereby a predetermined number of consecutively received tag device DTOA data (that is, a sample size n) are averaged to establish a mean DTOA. Advantageously, by using this type of statistical function, the DTOA for a particular tag device may be provided with an improvement in accuracy which is proportional to $\sqrt{n}$.

For a given DTOA between two receivers 14, the position of an athlete may be calculated as being on the surface of a hyperboloid. For a three receiver 14 solution the spatial position of an athlete may be calculated as the intersection of two hyperboloids. The ability of a system of the present invention to calculate the spatial position of an athlete in two or three dimensions is somewhat dependant upon the positioning of the antennas 46 within the monitored environment 12. In a particularly preferred embodiment of the present invention, the antennas 46 may be positioned in the same horizontal plane. In this embodiment, the solution of the hyperboloids is able to provide a two dimensional estimate of the spatial position of an athlete's location, based upon an assumption that the athlete is competing 'on the surface' of a playing field within the monitored environment 12. In an alternative embodiment of the present invention, the antennas 46 may be displaced from one another vertically. In this embodiment, the spatial location of an athlete may be determined in three dimensions.

Once the position of a tag device has been calculated, the DSP 78 communicates tag device position data, together with associated physiological and tag device identifier data to the data server 20. The data server 20

maintains and stores one or more athlete characteristics in the form of a chronological log of athlete positional characteristics (derived from the tag device position data) and a data log of physiological characteristics (derived from data recorded by tag device transducers) during the course of competition.

In the preferred embodiment of the data server 20, the data server 20 may be a programmed computer which includes an open architecture database application which enables stored data pertaining to the one or more athlete characteristics to be analysed, sorted, filtered and viewed in accordance with user instructions (for example, an operator of an analyst station).

In a particularly preferred form of the data server 20, the database server may include a multi-processor computer (for example, a Sun Microsystems Sun Fire mid-frame server) programmed with Oracle application software. In this form, the data server 20, may enable the construction of a web style client/server interface and graphical user interface (GUI) for the analyst stations 22. Preferably, the data server 20 is able to update the database in real time, and provide processed information to one or more display devices.

The data server 20 may also provide athlete characteristics data via a HTML server 26 to web browsers on the Internet or Intranet. Furthermore, the data server may also provide the athlete characteristics data to a media server 24 which preferably enables the information to be converted into industry standard protocols required for television or radio broadcast.

In the preferred embodiment of the invention, the analyst stations 22 are electrically coupled to the data server via an industry standard interface (for example, IEEE 802.3u) and operable by an operator to provide an operator with the capability to retrieve and display selected characteristics for one or more selected athletes in real time, or to replay characteristics of one or more athletes which were recorded during a particular interval (for example, display the track of an athlete used to evade an opponent's tackle).

With reference to Figure 6, there is illustrated an example of a GUI that may be suitable for use in a preferred embodiment of an analyst station 22 for the display of one or more athlete characteristics during, or following, a basketball game. The GUI preferably includes multiple 'panes', namely a 'video in a window' and game status pane 80, an athlete selection pane 82, a physiological characteristics display pane 84 and a position display pane 86. The GUI may also include a menu toolbar 88 which provides an operator with display controls.

In the preferred embodiment of the invention, the media server 24 may be a Silicon Graphics Incorporated (SGI) visual workstation (for example, a SGI Octane) programmed with customised computer software. In this form, the media server 24 may provide an integrated computing platform for serving video, audio and data, based on open video I/O, data networking I/O and storage technology.

The invention described herein is susceptible to variations, modifications and/or additions other than those specifically described and it is to be understood that the invention includes all such variations, modifications and/or additions that fall within the spirit and scope of the invention.

Claims:

1. A system for monitoring and displaying characteristics of one or more athletes, the system including:

(a.) a plurality of tag devices, each tag device being capable of periodically transmitting a tag device signal in the form of a short burst, frequency-hopped spread spectrum radio frequency signal, at least one tag being located on each athlete;

(b.) at least three separately located wideband receivers, each receiver being capable of receiving a tag device signal and being capable of processing the tag device signal to provide data representative of the time of arrival of the tag device signal at the receiver;

(c.) a centralised processing means capable of receiving and processing the time of arrival data from each receiver to determine the position of the tag device using differences in the time of arrival data from each receiver;

(d.) a data server capable of storing the positions determined by the centralized processing means; and

(e.) a means for retrieving and processing data from the data server to enable a graphical representation of at least one selected athlete characteristic to be displayed.

2. A system according to claim 1 wherein the transmitting of a tag device signal by a tag device occurs asynchronously in time and/or frequency with the transmission of tag device signals by other tag devices.

3. A system according to claim 2 wherein the tag device signal transmitted by a tag device has a carrier frequency which has been selected from a discrete number of frequencies within a predetermined frequency band, the carrier frequency being selected by a channel number generator on board the tag device.

4. A system according to claim 3 wherein the channel number generator selects the carrier frequency of a tag device signal using a spreading sequence.

5. A system according to claim 4 wherein the channel number generator is a pseudo random binary sequence generator and the spreading sequence is a pseudo random binary sequence.

6. A system according to claim 1 wherein the periodic transmission of a tag device signal by a tag device occurs at a pulse repetition frequency, each tag device having a unique pulse repetition frequency.

7. A system according to claim 1 wherein the tag device signal includes a modulated portion and an unmodulated portion.

8. A system according to claim 7 wherein the modulated portion contains data.

9. A system according to claim 8 wherein the data includes:
   (a.) identification data; or
   (b.) sensor data.

10. A system according to claim 8 wherein the data includes:
   (a.) identification data; and
   (b.) sensor data.

11. A system according to claim 9 or claim 10 wherein the identification data includes:
   (a.) a tag device identifier which identifies the tag device which has transmitted a tag device signal; or
   (b.) an athlete identifier, the athlete identifier identifying the athlete on which the tag device is located.

12. A system according to any one of claims 9 to claim 11 wherein the sensor data is obtained from one or more sensors having an interface to the tag device.

13. A system according to claim 12 wherein one or more of the sensors are incorporated within the tag device.

14. A system according to claim 13 wherein the sensors include sensors for providing a signal which is indicative of physiological characteristics of an athlete having a tag device.

15. A system according to claim 14 wherein the types of sensors which are able to be interfaced to the tag device include:

(a.) heart rate sensors;

(b.) skin temperature sensors; and

(c.) relative humidity sensors.

16. A system according to claim 3 wherein each receiver includes:

(a.) an antenna for sensing the tag device signals;

(b.) a down converter for converting a sensed tag device signal to an intermediate frequency signal;

(c.) an analog to digital converter for digitising the intermediate frequency signal to provide a digital representation of the intermediate frequency signal; and

(d.) processing means for processing the digital representation of the intermediate frequency signal to provide time of arrival data and communicating the time of arrival data to the centralized processing means;

wherein the down-conversion of the sensed tag device signal occurs without knowledge of the spreading sequence used to generate the carrier frequency for the tag device signal.

17. A system according to claim 16 wherein the down converter includes a local oscillator having a fixed frequency.

18. A system according to claim 16 wherein the processing means includes demodulation means for demodulating the modulated portion of the tag device signal to provide demodulated data wherein the demodulated data is communicated to the centralised processing means together with the time of arrival data.

19. A system according to claim 16 or claim 18 wherein the processing means further includes:

(a.) pulse envelope detection means for providing a video signal which is proportional to the envelope of the digital representation of the intermediate frequency signal;

(b.) a delay means;

(c.) an attenuator means;

(d.) a comparator means; and

(e.) a free running counter, the free running counter being synchronised to a system clock

wherein the delay means acts on the video signal to provide a delayed signal having a predetermined delay with respect to the video signal, the attenuator means acts on the video signal to provide an attenuated signal, and wherein the comparator compares the leading edge of the attenuated signal to the leading edge of the delayed signal so as to provide a trigger signal for obtaining the count of the free running counter when the amplitude of the delayed signal intersects the amplitude of the attenuated signal, the count being representative of the time of arrival of the tag device signal at the receiver.

20. A system according to claim 9 or 10 wherein the centralised processing means includes:

(a.) at least one signal processing means, each signal processing means being associated with one or more of the tag devices; and

(b.) a routing means for routing tag device data received from each receiver to a selected signal processing means, the signal processing means being selected according to the tag device identification data;

wherein each signal processing means calculates differential time of arrival data using the time of arrival data for a respective tag device and calculates position data for the respective tag device using the differential time of arrival data.

21. A system according to claim 20 wherein if the modulated portion of received tag device signal is corrupted, the router selects the signal processing means using the time of arrival data.

22. A system according to claim 21 wherein the selection of a signal processing means for a corrupted tag device signal occurs if the time of arrival of the corrupted signal occurs within a temporal window which includes the time of arrival of a tag device signal having uncorrupted identification data, such that the selected processing device is the same as that selected for the identified tag device.

23. A system according to claim 22 wherein the temporal window is the maximum propagation time for a tag device signal to traverse across a monitored environment to a particular receiver.

24. A system according to claim 20 wherein the calculation of the position data is performed using hyperbolic fixing.

25. A system according to claim 1 wherein the centralised processing means includes means for calculating time derivatives of the position data for a tag device.

26. A system according to claim 25 wherein the time derivatives of position data for a tag device include:

(a.) velocity; and/or

(b.) acceleration.

27. A system according to claim 25 wherein the athlete characteristics which are able to be selected include:

(a.) the position of an athlete having a tag device in a monitored environment; and

(b.) the time derivatives of the position of an athlete having a tag device in the monitored environment.

28. A system according to claim 25 wherein the tag device signal contains data, the data including sensor data obtained from one or more sensors having an interface to the tag device, and the athlete characteristics which are able to be selected include:

(a.) the position of an athlete having a tag device in a monitored environment;

(b.) time derivatives of the position of the athlete in the monitored environment; and

(c.) characteristics which are obtained from the sensor data.

29. A system according to claim 1 wherein the means for retrieving and processing data from the data server to enable a graphical representation of at least one selected athlete characteristic to be displayed is a web server.

30. A system for monitoring and displaying characteristics of one or more objects in a monitored environment, the system including:

(a.) a plurality of tag devices, each tag being attached to an object and being capable of periodically transmitting a tag device signal in the form of a short burst, frequency-hopped spread spectrum radio frequency signal, the carrier frequency of a tag device signal being selected according to a spreading sequence generated by a channel number generator on board each tag device such that the

transmission of a tag device signal by a tag device occurs asynchronously in time and/or frequency with the transmission of tag device signals by other tag devices;

(b.) at least three separately located wideband receivers, each receiver being located contiguous to the monitored environment and being capable of receiving a tag device signal, the receiver including a down converter which down converts the tag device signal to an intermediate frequency signal, the down conversion occurring without knowledge of the spreading sequence, the receiver being capable of processing the tag device signal to provide data representative of the time of arrival of the tag device signal at the receiver using the leading edge of the pulse envelope of the intermediate frequency signal;

(c.) a centralised processing means capable of receiving and processing the time of arrival data from each receiver to determine the position of the tag device using differences in the time of arrival data from each receiver;

(d.) a data server capable of storing the positions determined by the centralized processing means; and

(e.) a means for retrieving and processing data from the data server to enable a graphical representation of at least one selected object characteristic to be displayed, the selectable object characteristics including:

i. the position of the object in the monitored environment; or

ii. time derivatives of the position of the object in the monitored environment.

31. A system according to claim 30 wherein the monitored environment is a sporting facility.

32. A method for monitoring and displaying characteristics of one or more athletes having a tag device capable of periodically transmitting a short

burst frequency-hopped spread spectrum (FH-SS) radio frequency (RF) signal, the method including:

(a.) receiving a tag device signal using at least three separately located wideband receivers;

(b.) processing the tag device signal to provide data representative of the time of arrival of a tag device signal at each receiver;

(c.) processing the time of arrival data to determine the position of the tag device using differences in the time of arrival data from each receiver;

(d.) storing the positions on a data server; and

(e.) retrieving and processing position data from the data server to enable a graphical representation of at least one selected athlete characteristic to be displayed.

33. A method according to claim 32 wherein tag device signals are transmitted using a carrier frequency which has been selected using a spreading sequence provided by a channel number generator on board the tag device and the step of receiving of the tag device signal by a receiver includes down converting the tag device signal to an intermediate frequency signal without knowledge of the spreading sequence.

34. A method according to claim 32 wherein the tag device signals include a modulated portion and an unmodulated portion, the modulated portion including identification data or sensor data.

35. A method according to claim 34 wherein the step of processing the tag device signal to provide data representative of the time of arrival of a tag device signal at each receiver further includes demodulating the modulated portion of the tag device signal to recover identification data or sensor data.

36. A method according to claim 32 wherein tag device signals are transmitted asynchronously in time and/or frequency.

37. A method according to claim 33 wherein the processing of the tag device signal to provide data representative of the time of arrival of the tag device signal is performed using the leading edge of the pulse envelope of the intermediate frequency signal.

38. A method according to claim 32 wherein the athlete characteristics which are able to be selected include:

(a.) the position of the object in the monitored environment; or

(b.) time derivatives of the position of the object in the monitored environment.

39. A method according to claim 32 wherein the athlete characteristics which are able to be selected include:

(a.) the position of the object in the monitored environment;

(b.) time derivatives of the position of the object in the monitored environment; or

(c.) characteristics which are obtained from the sensor data.

40. A method for monitoring and displaying characteristics of one or more objects in a monitored environment, the method including:

(a.) a plurality of tag devices periodically transmitting a tag device signal in the form of a short burst, frequency-hopped spread spectrum radio frequency signal, the carrier frequency of a tag device signal being selected according to a spreading sequence generated by a channel generator on board each tag device such that the transmission of a tag device signal by a tag device occurs asynchronously in time and/or frequency with the transmission of tag device signals by other tag devices, each tag device being attached to an object;

(b.) receiving a tag device signal using at least three separately located wideband receivers, each receiver being located contiguous to the monitored environment, the receiver down converting the tag device signal to an intermediate frequency signal, the down conversion occurring without knowledge of the spreading sequence, the receiver processing the tag device signal to provide data representative of the time of arrival of the tag device signal at the receiver using the leading edge of the pulse envelope of the intermediate frequency signal;

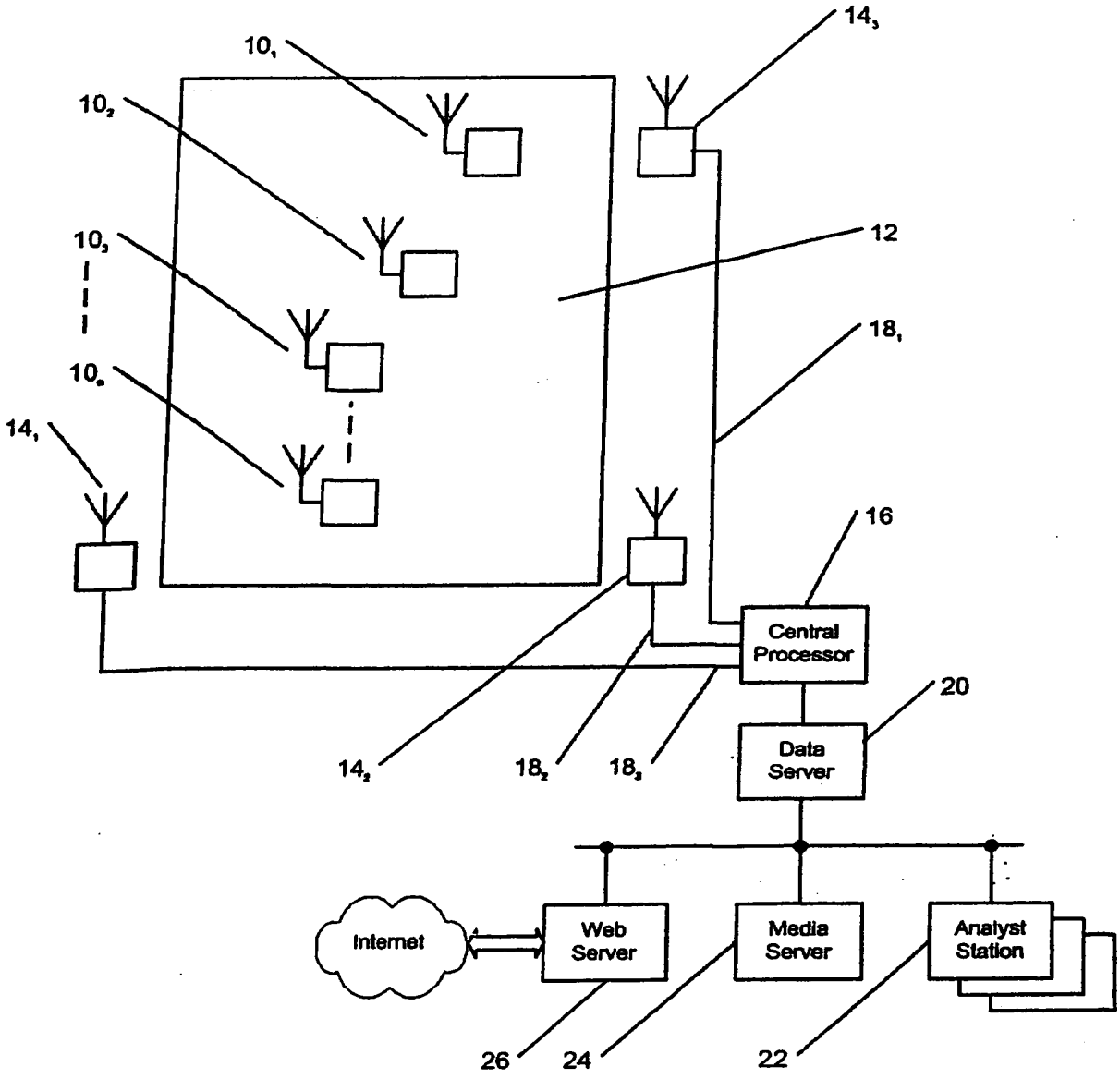
(c.) a centralised processing receiving and processing the time of arrival data from each receiver and determining the position of the tag device using differences in the time of arrival data from each receiver;

(d.) a data server storing the positions determined by the centralized processing means; and

(e.) retrieving and processing data from the data server to provide a graphical representation of at least one selected object characteristic to be displayed, the selectable object characteristics including:

i. the position of the object in the monitored environment; or

ii. time derivatives of the position of the object in the monitored environment.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10,
10,
10,
14,
14,
12
18,
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Central Processor
20
Data Server
14,
18,
18,
Internet
Web Server
Media Server
Analyst Station
26
24
22

Figure 1

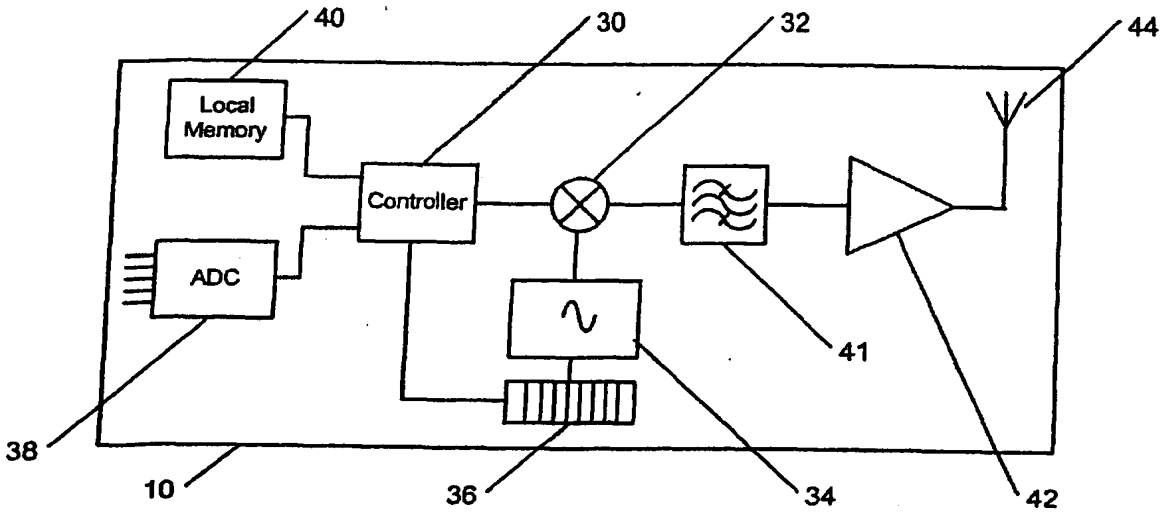


Figure 2

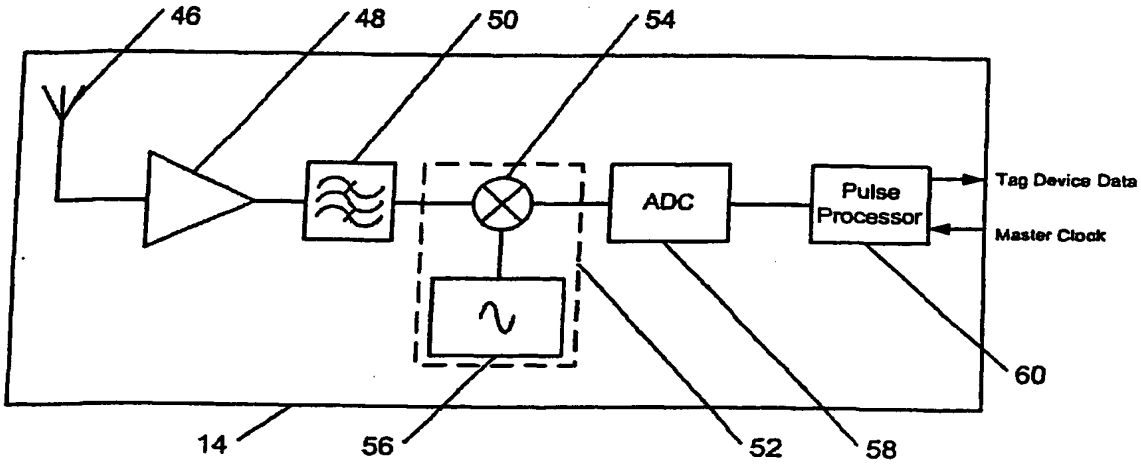
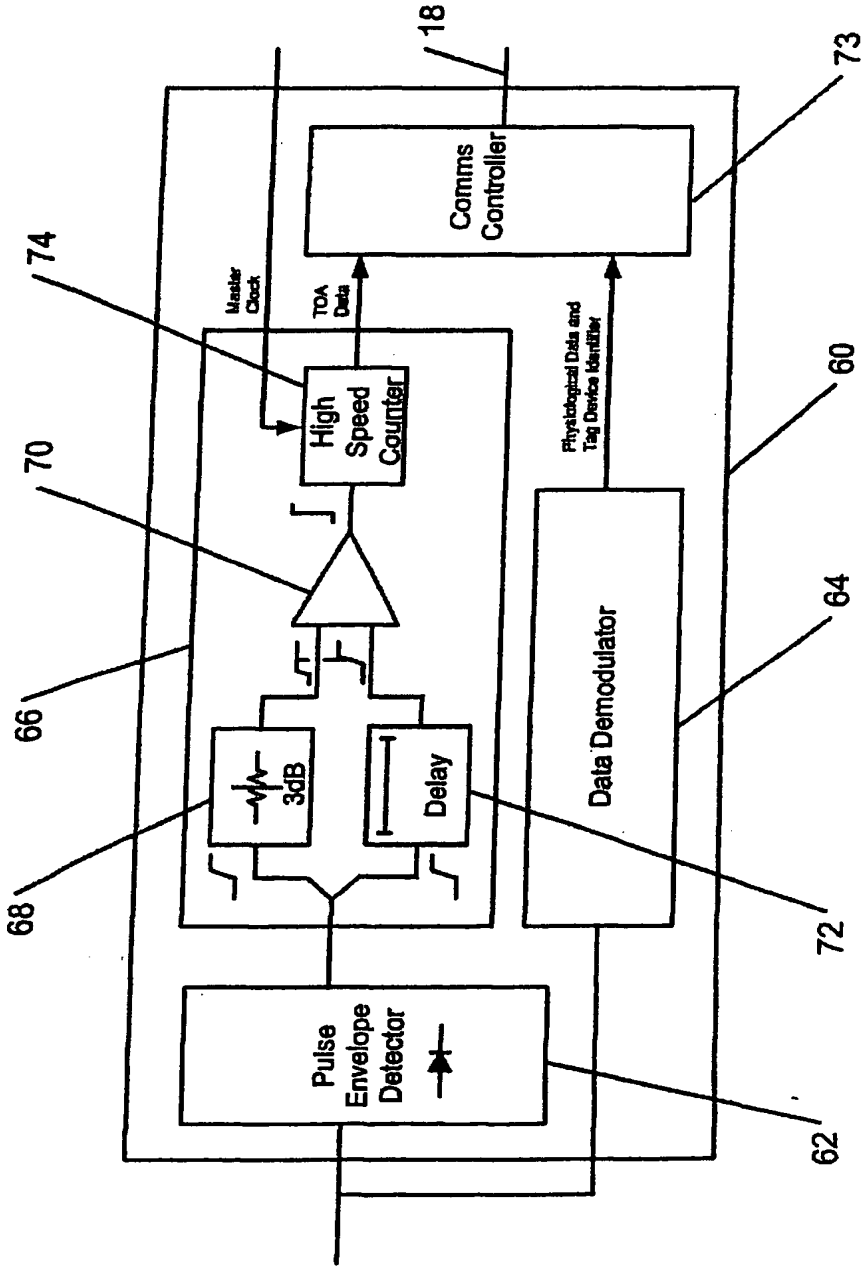


Figure 3


18
73
Comms Controller
74
Master Clock
TOA Data
Physiological Data and Tag Device Identifier
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High Speed Counter
70
64
66
3dB
Delay
Data Demodulator
68
72
Pulse Envelope Detector
62

Figure 4

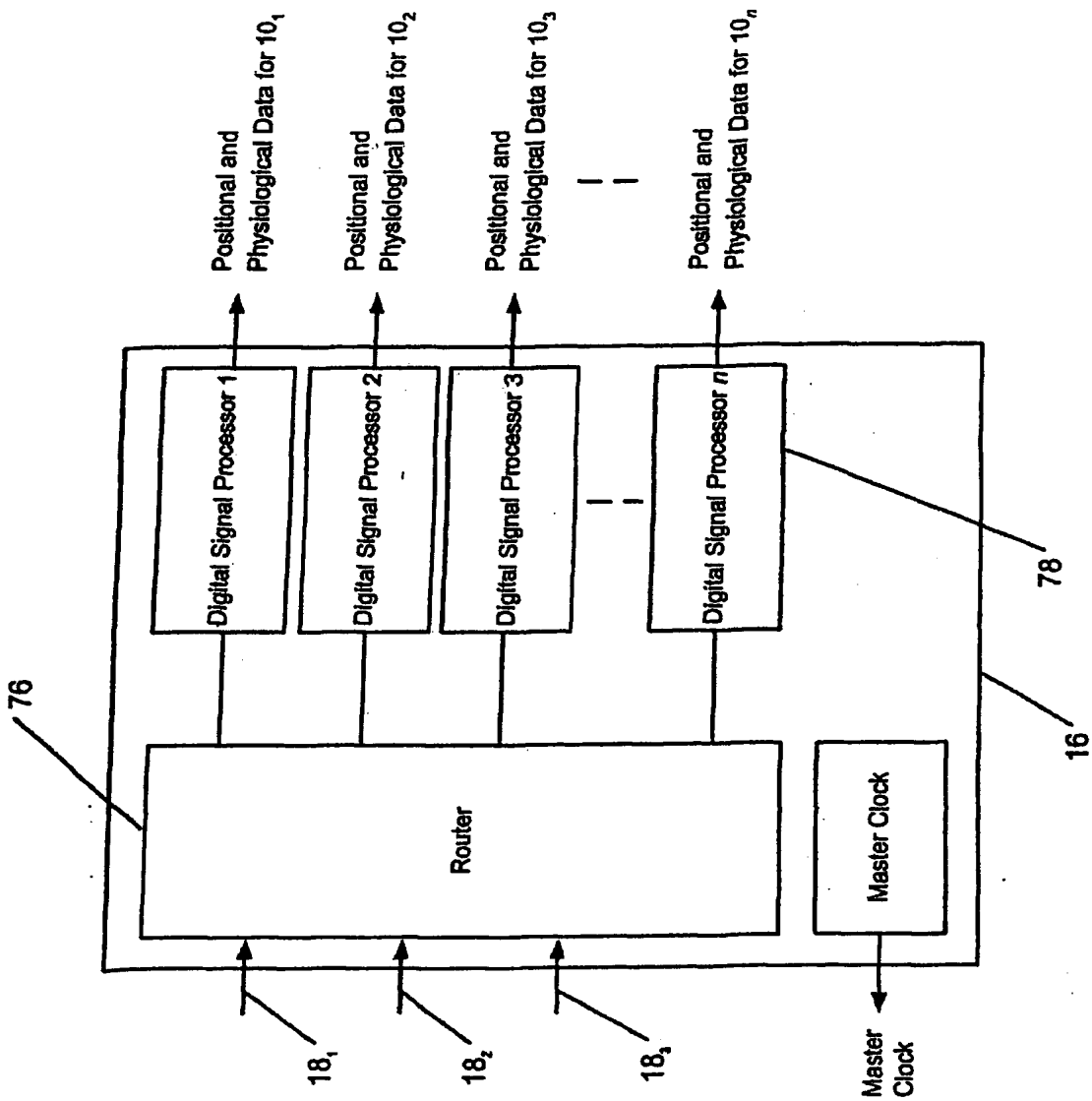
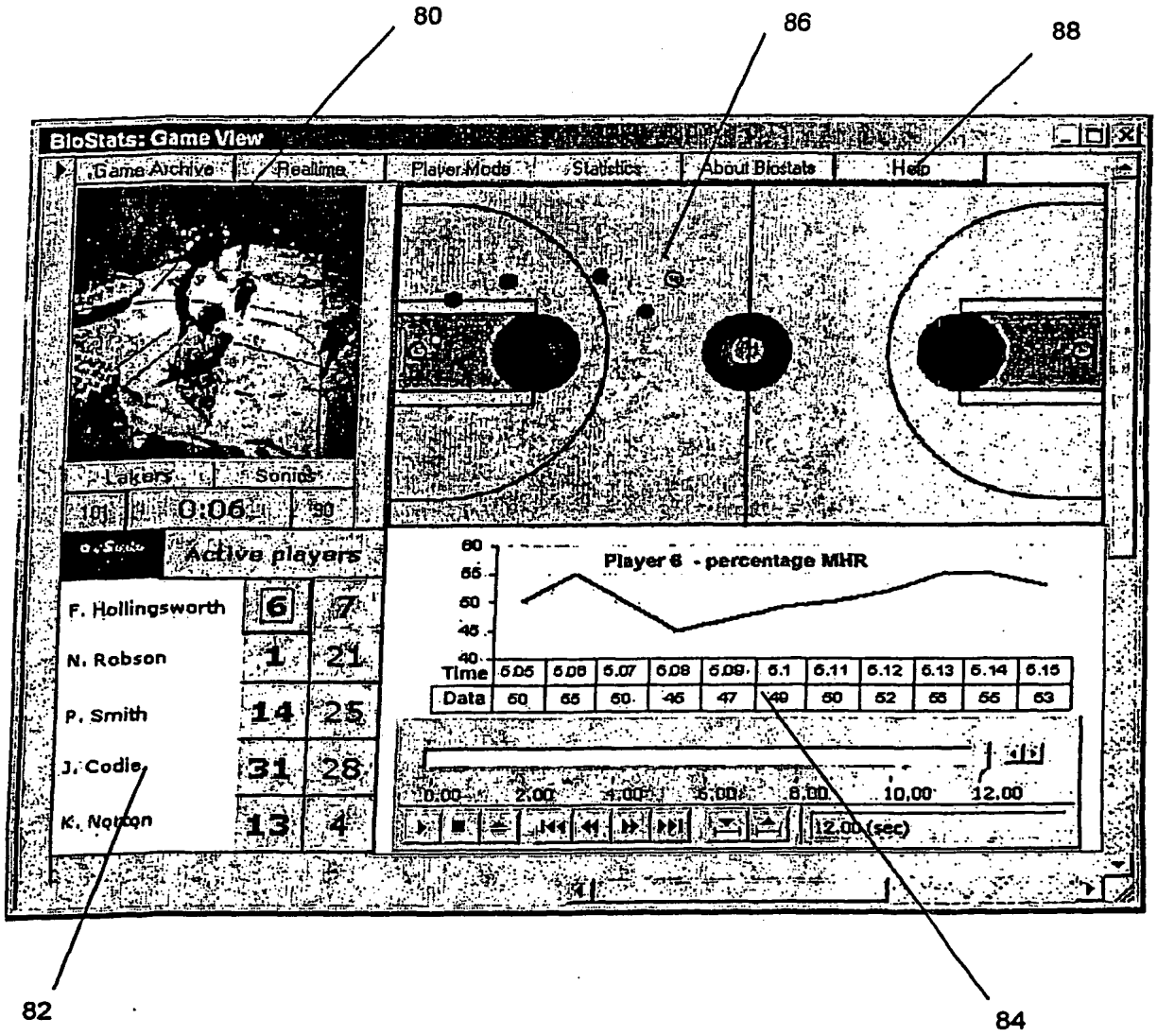

Positional and Physiological Data for 10_1
Positional and Physiological Data for 10_2
Positional and Physiological Data for 10_3
Positional and Physiological Data for 10_n
Digital Signal Processor 1
Digital Signal Processor 2
Digital Signal Processor 3
Digital Signal Processor n
78
76
Router
Master Clock
16
18_1
18_2
18_3
Master Clock

Figure 5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Game Archive
Realtime
Player Mode
Statistics
About Biostats
Help
Lakers
Sonics
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Active players
F. Hollingsworth
6
7
N. Robson
1
21
P. Smith
14
25
J. Codie
31
28
K. Norton
13
4
Player 6 - percentage MHR
60
55
50
45
40
Time
5.05
5.06
5.07
5.08
5.09
5.1
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55
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53
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12.00 (sec)
82
84

Figure 6

INTERNATIONAL SEARCH REPORT

International application No.
PCT/AU02/00760

A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl. [7]: G01S 5/14, 5/06

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
refer electronic database consulted below

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
DWPI: G01S and keywords (receiver sport athlete position location time delay and like terms)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 6 204 813 B1 (WADELL et al) 20 March 2001 Column 3 line 33 to column 5 line 21	1-40
X	US 5 150 310 A (GREENSPUN et al) 22 September 1992 Column 4 line 64 to column 6 line 11	1, 2, 6, 32, 36, 40

☐ Further documents are listed in the continuation of Box C ☒ See patent family annex

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search
3 July 2002

Date of mailing of the international search report 11 JUL 2002

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.
PCT/AU02/00760

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report		Patent Family Member					
US	6204813	AU	64427/98	EP	969903	WO	9837932
US	5150310	NONE					

END OF ANNEX